

US007107514B1

(12) **United States Patent**  
**Oberg et al.**

(10) **Patent No.:** **US 7,107,514 B1**  
(45) **Date of Patent:** **Sep. 12, 2006**

(54) **METHOD AND APPARATUS FOR  
DETECTING VITERBI DECODER ERRORS  
DUE TO QUASI-CATASTOPHIC SEQUENCES**

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(BM)

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 531 days.

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(21) Appl. No.: **10/393,640**

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(22) Filed: **Mar. 21, 2003**

*Primary Examiner*—Guy J. Lamarre

**Related U.S. Application Data**

(57) **ABSTRACT**

(60) Provisional application No. 60/406,259, filed on Aug. 27, 2002.

A Viterbi decoder identifies errors in an early decision output and includes an early decision generator that generates the early decision output. A full decision generator generates a full decision output. An error detector detects errors in the early decision output and generates a disable signal. A secondary early decision generator generates a secondary early decision output. The error detector includes a comparing circuit that disables a prior early decision output if the secondary early decision output is different than the prior early decision output. Alternately, a best path flag generator generates a best path flag when the Viterbi decoder identifies two best paths having the same path metric. A comparing circuit disables the early decision output if a prior secondary early decision output is different than the early decision output, the best path flag is true and a prior best path flag is true.

(51) **Int. Cl.**  
**H03M 13/03** (2006.01)

(52) **U.S. Cl.** ..... **714/795**; 714/796; 714/794;  
375/346; 375/262; 375/265; 375/233

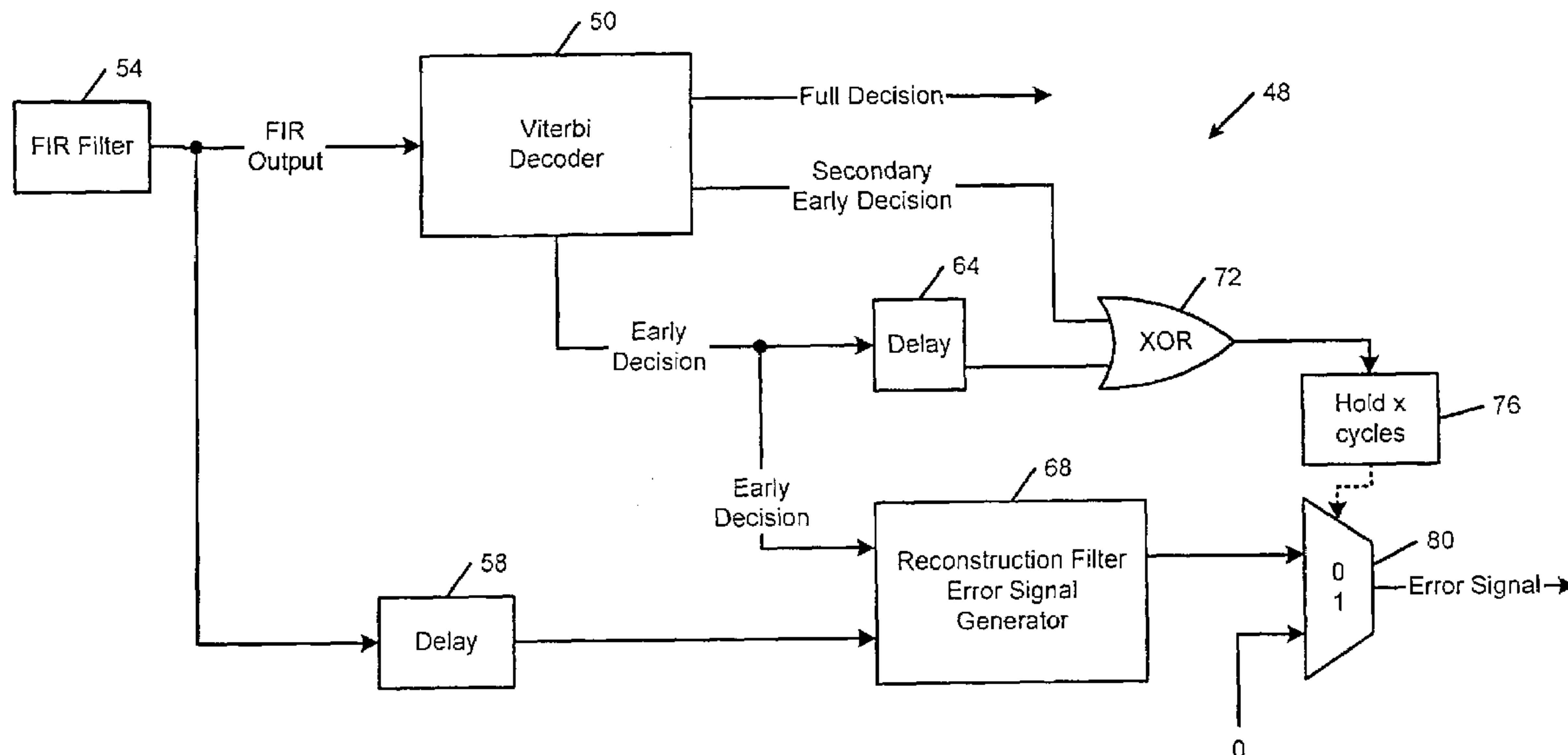
(58) **Field of Classification Search** ..... 714/794-796,  
714/791; 375/262, 341  
See application file for complete search history.

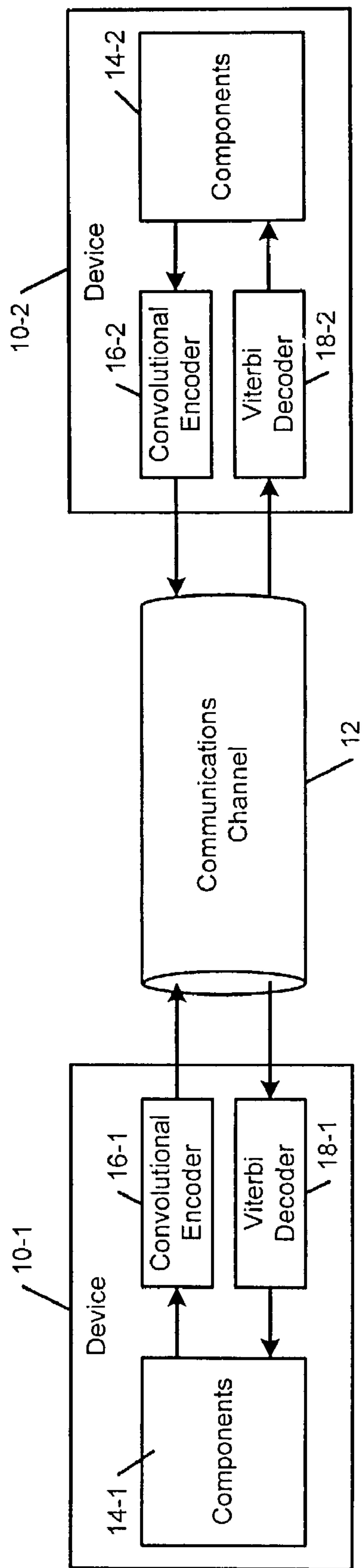
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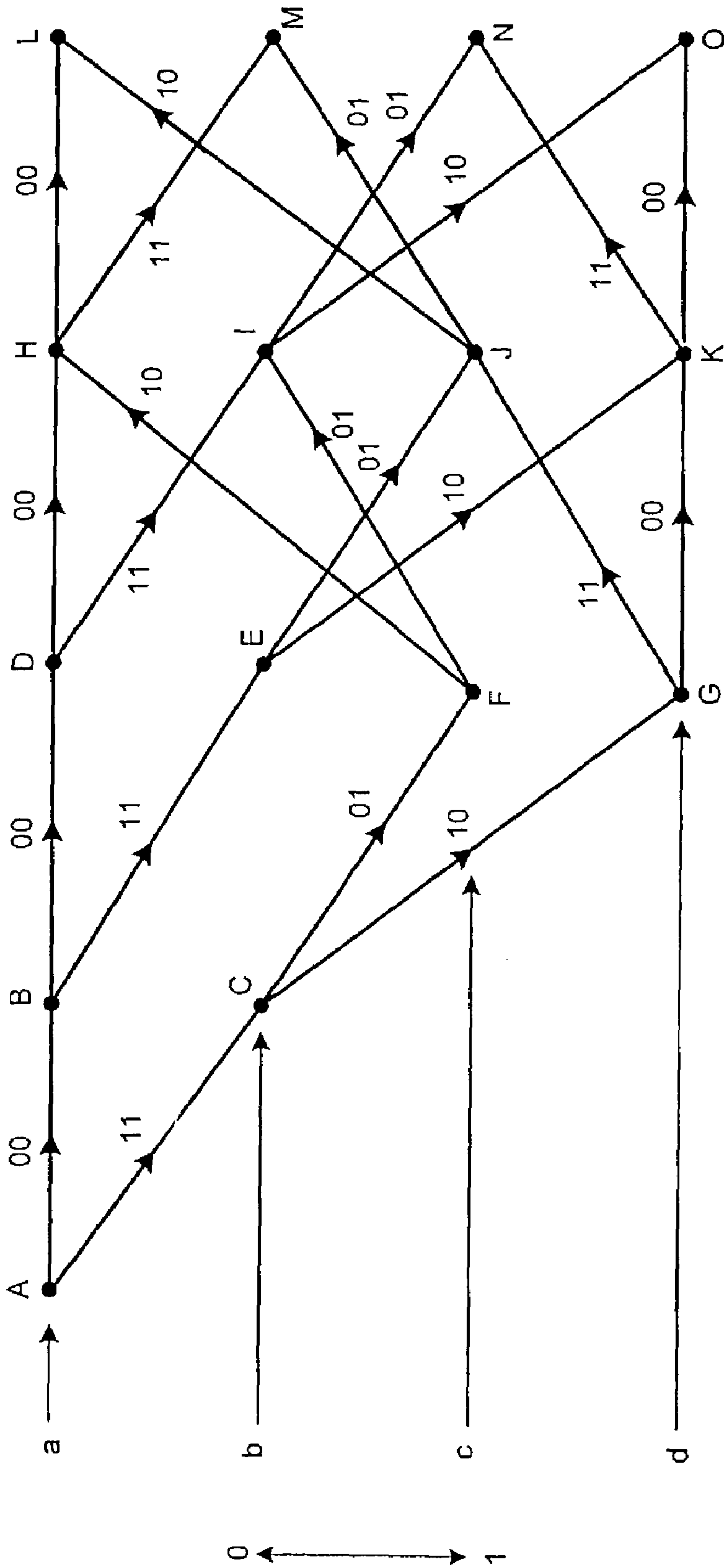
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**94 Claims, 11 Drawing Sheets**

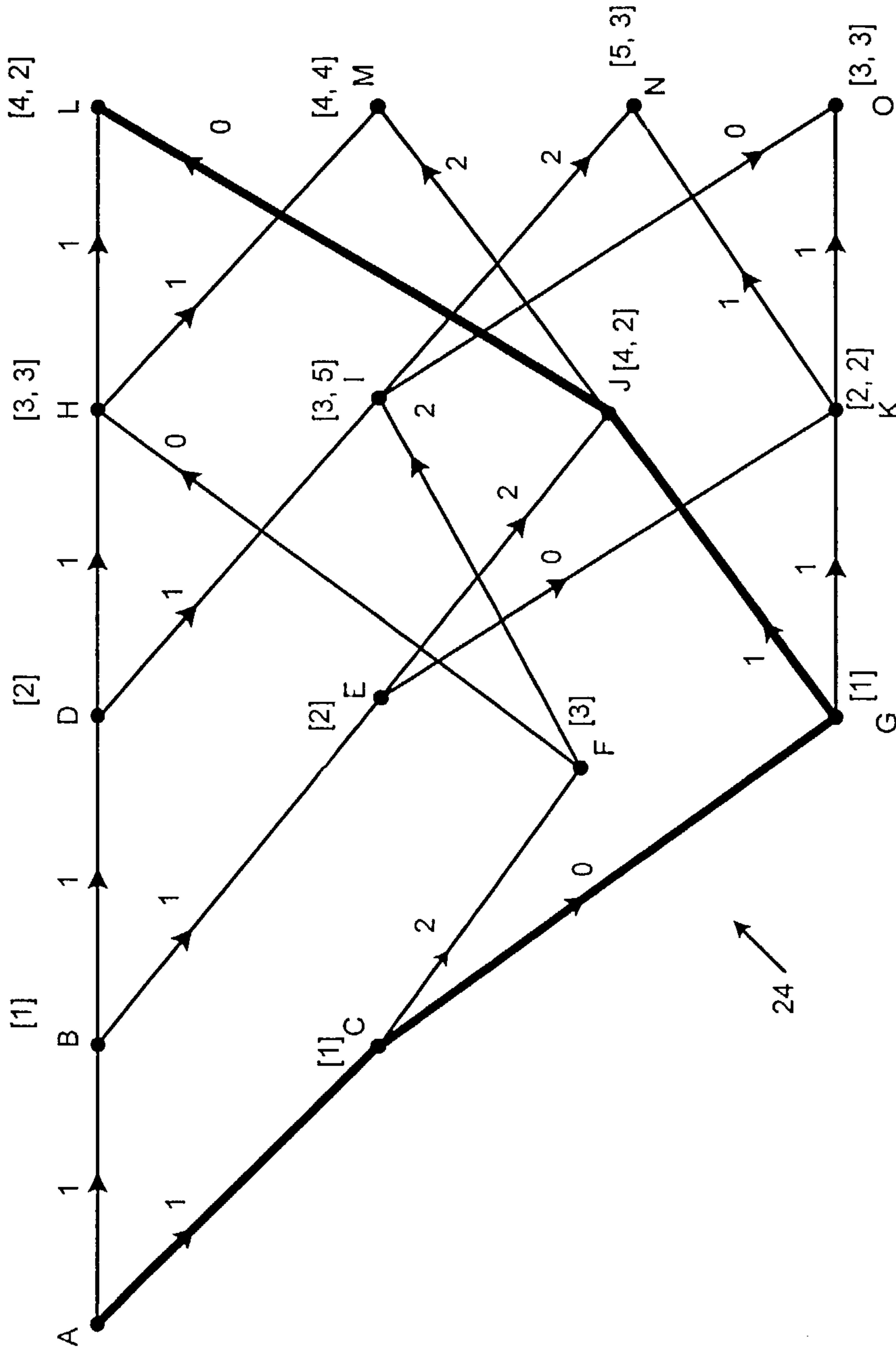




**FIG. 1**  
Prior Art

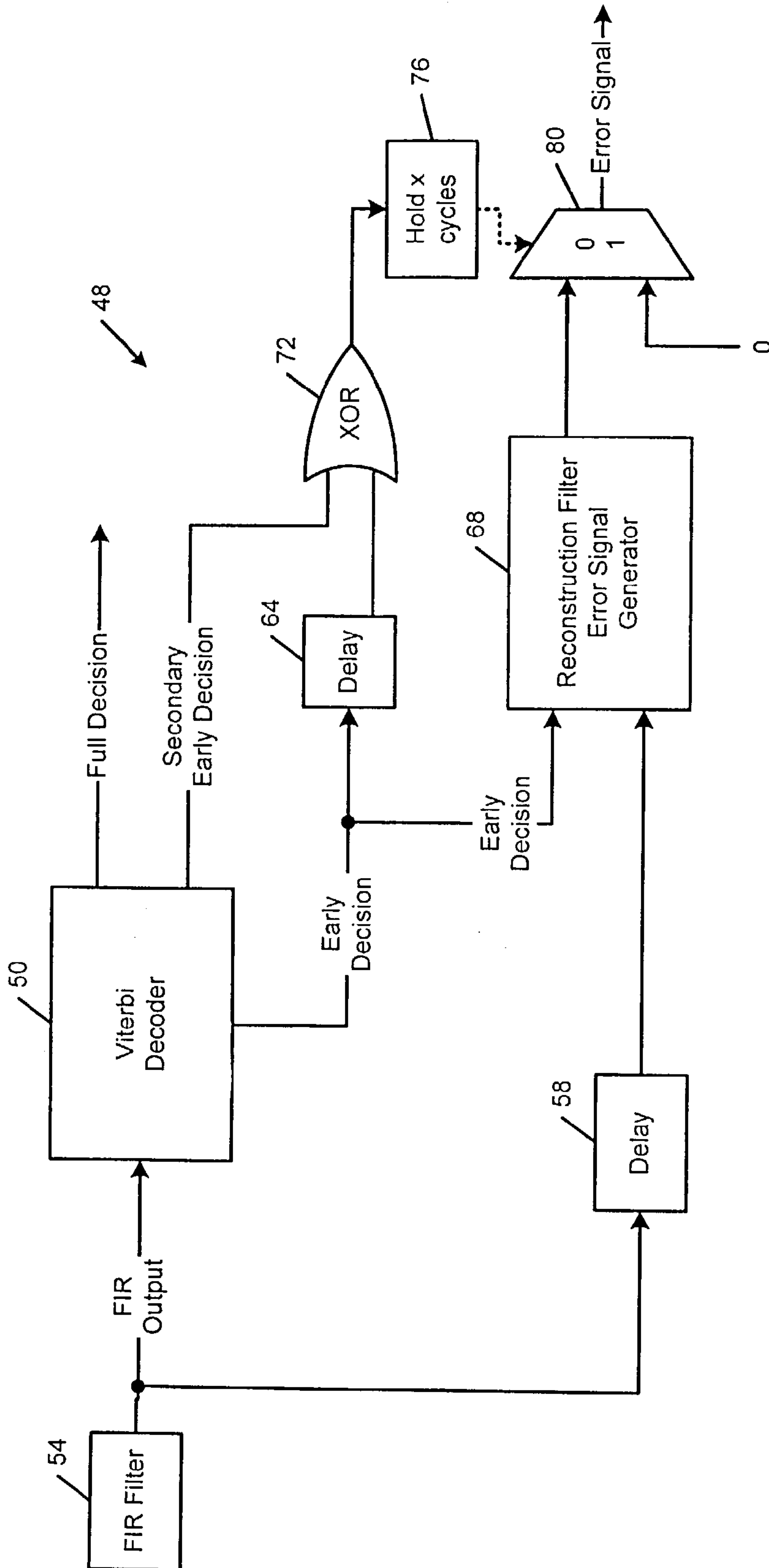


**FIG. 2**  
Prior Art

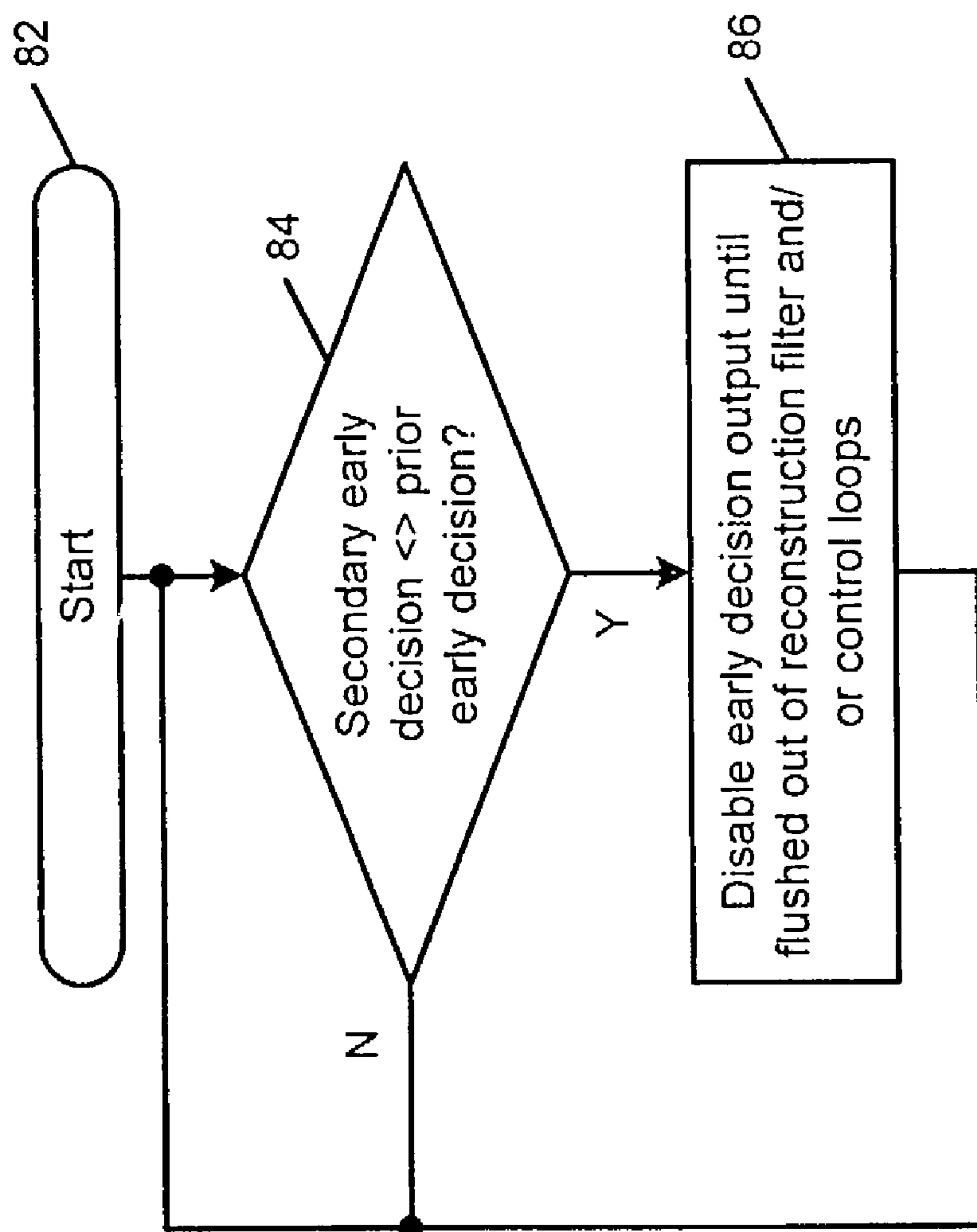


**FIG. 3**  
Prior Art

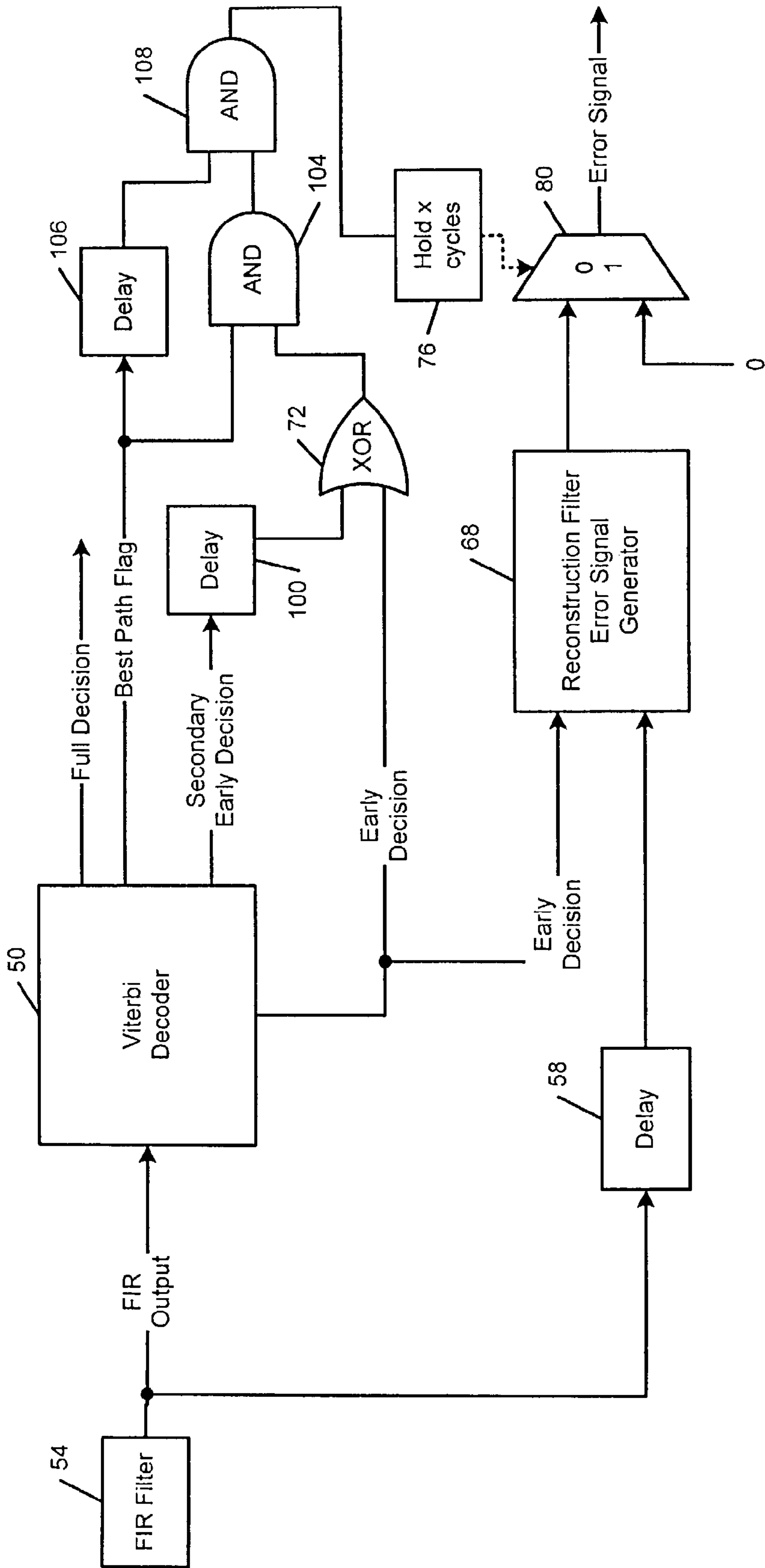
24



**FIG. 4**

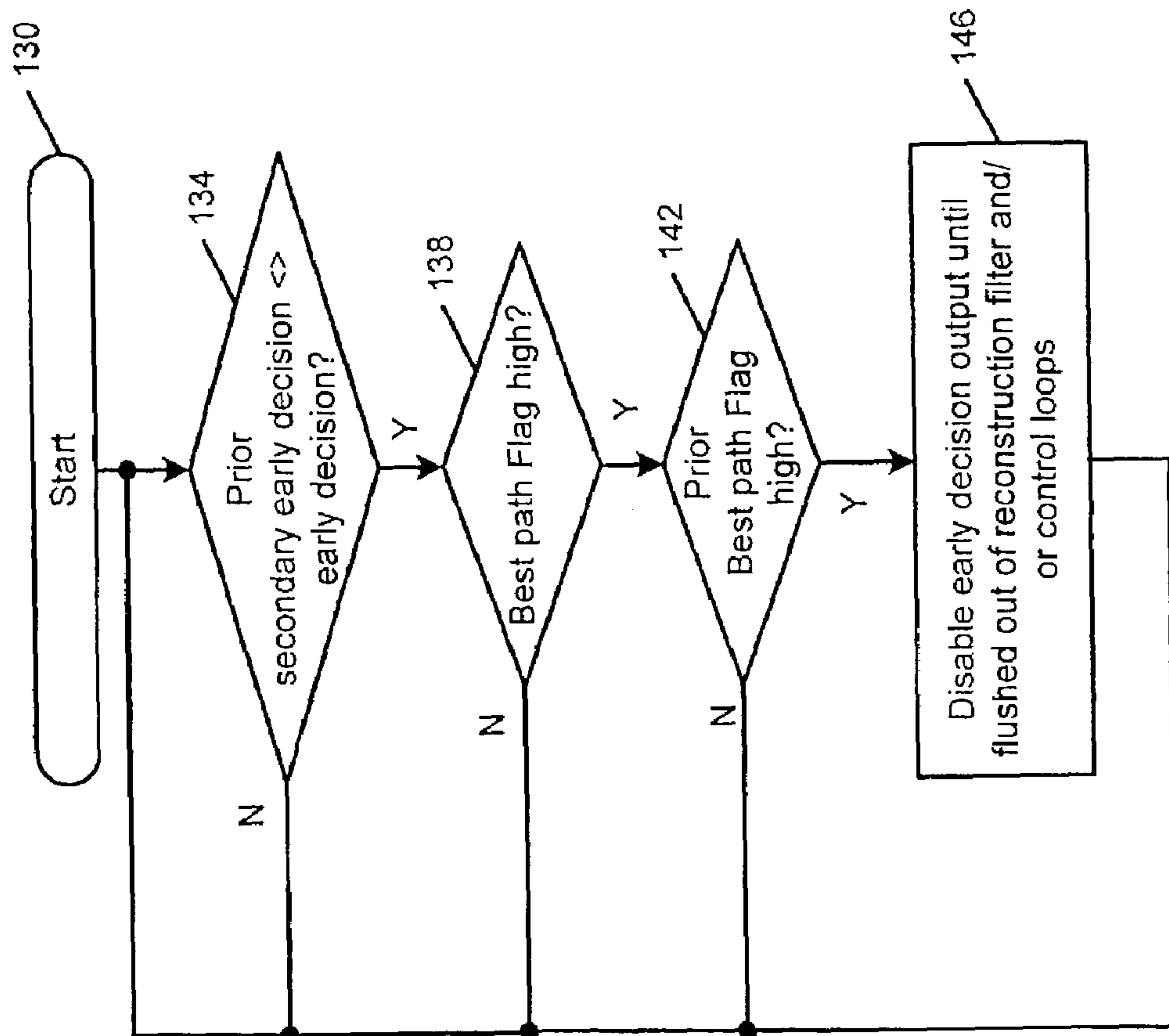


**FIG. 5**



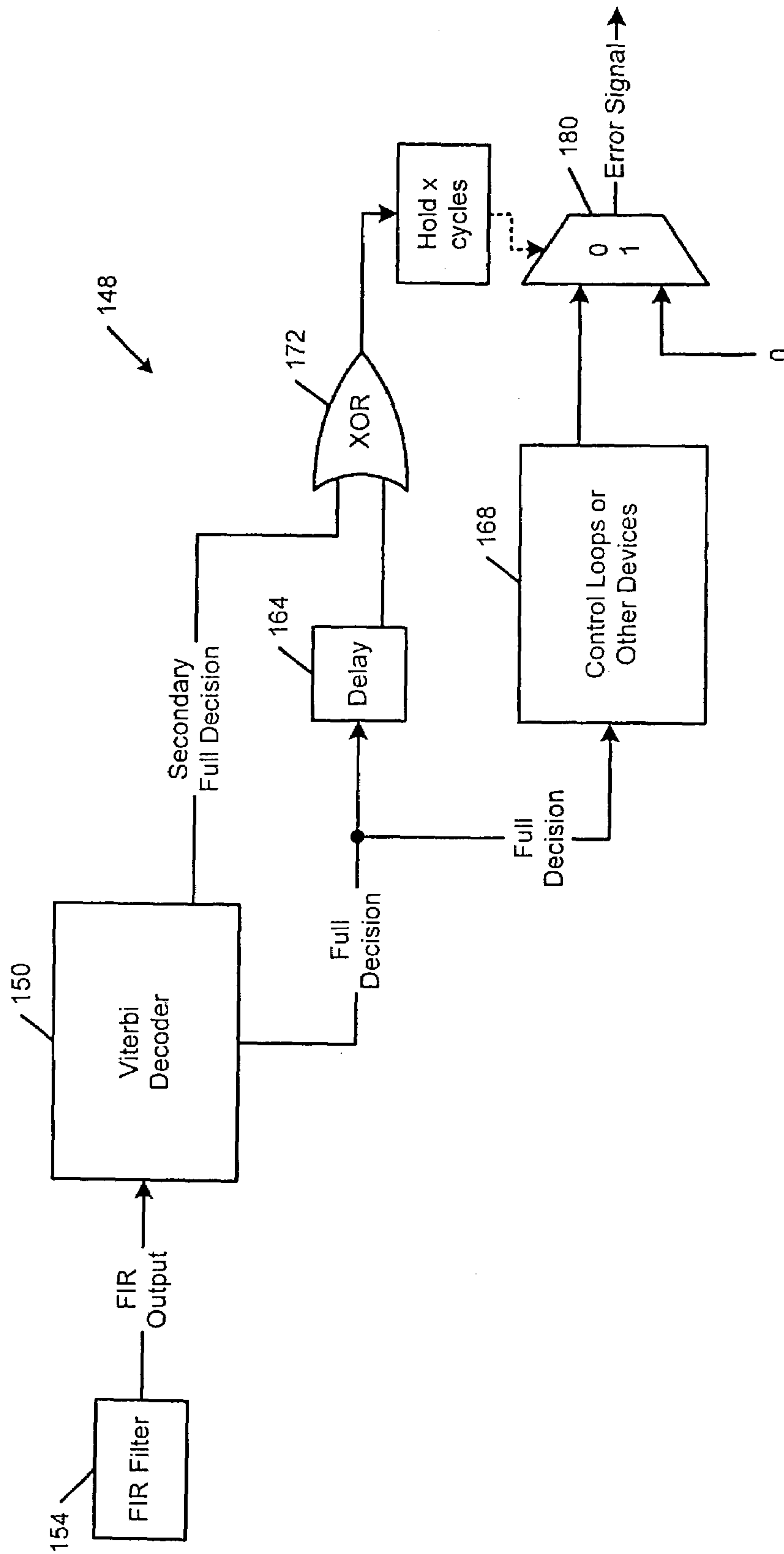
**FIG. 6**



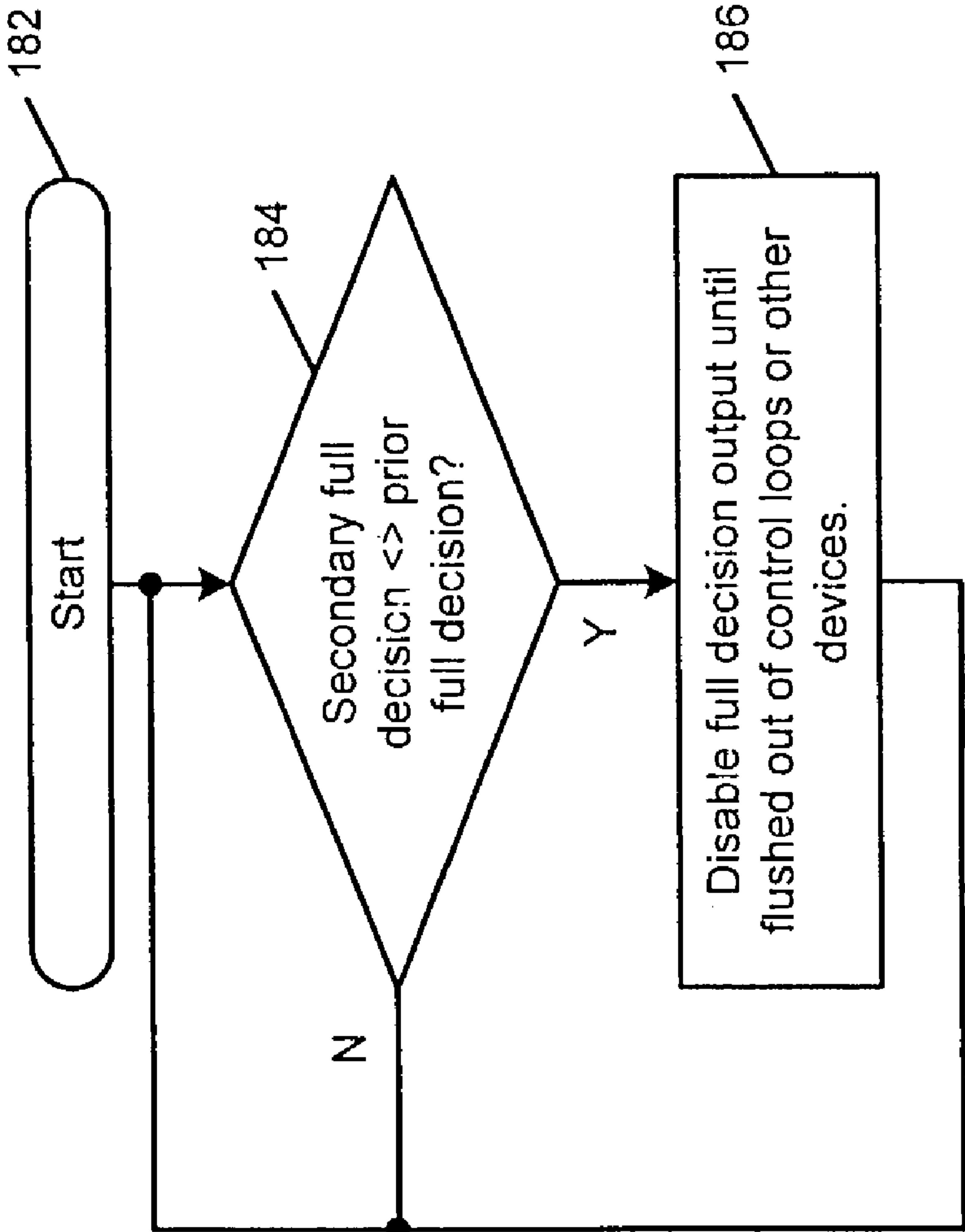


**FIG. 7**

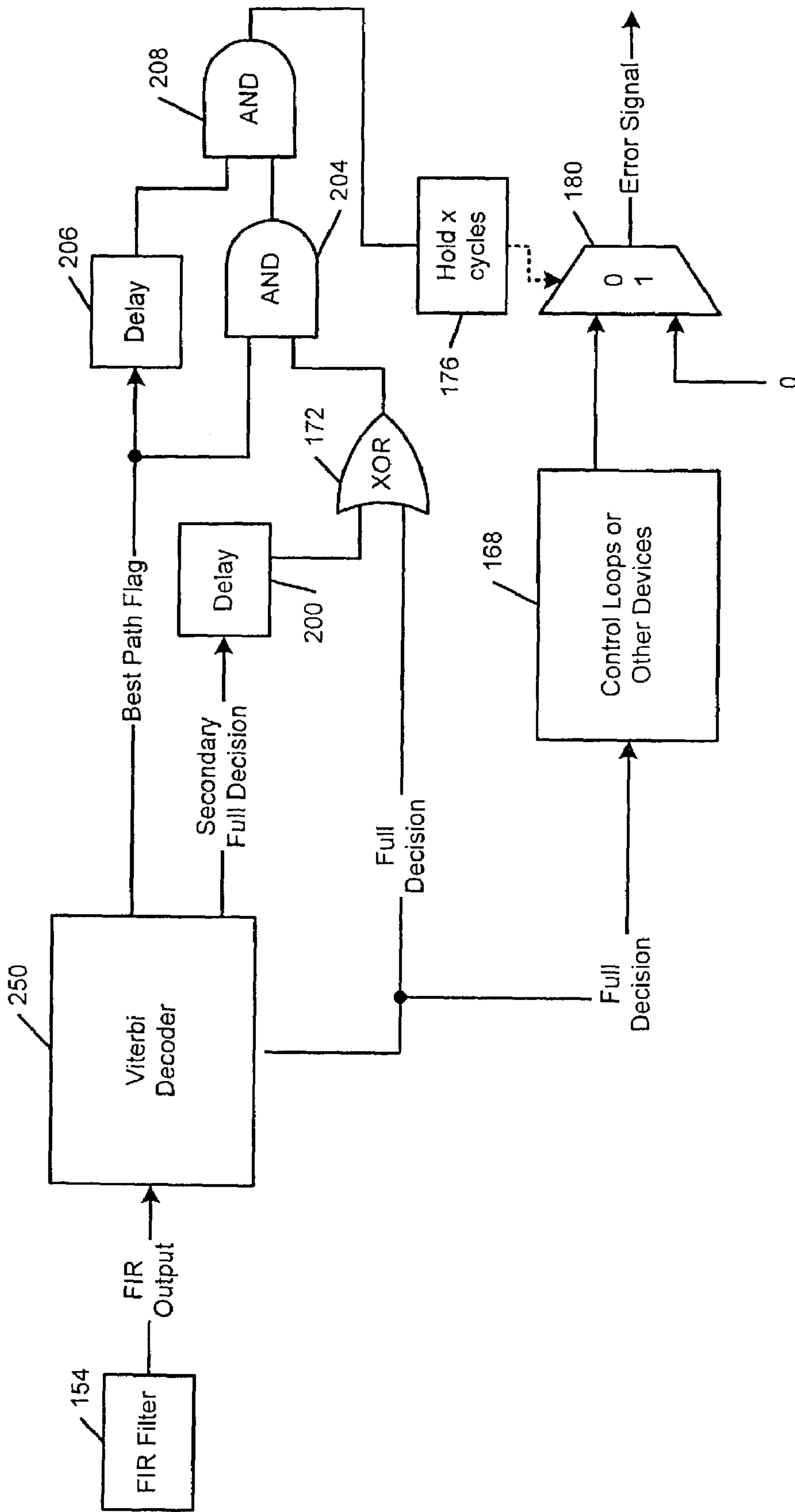




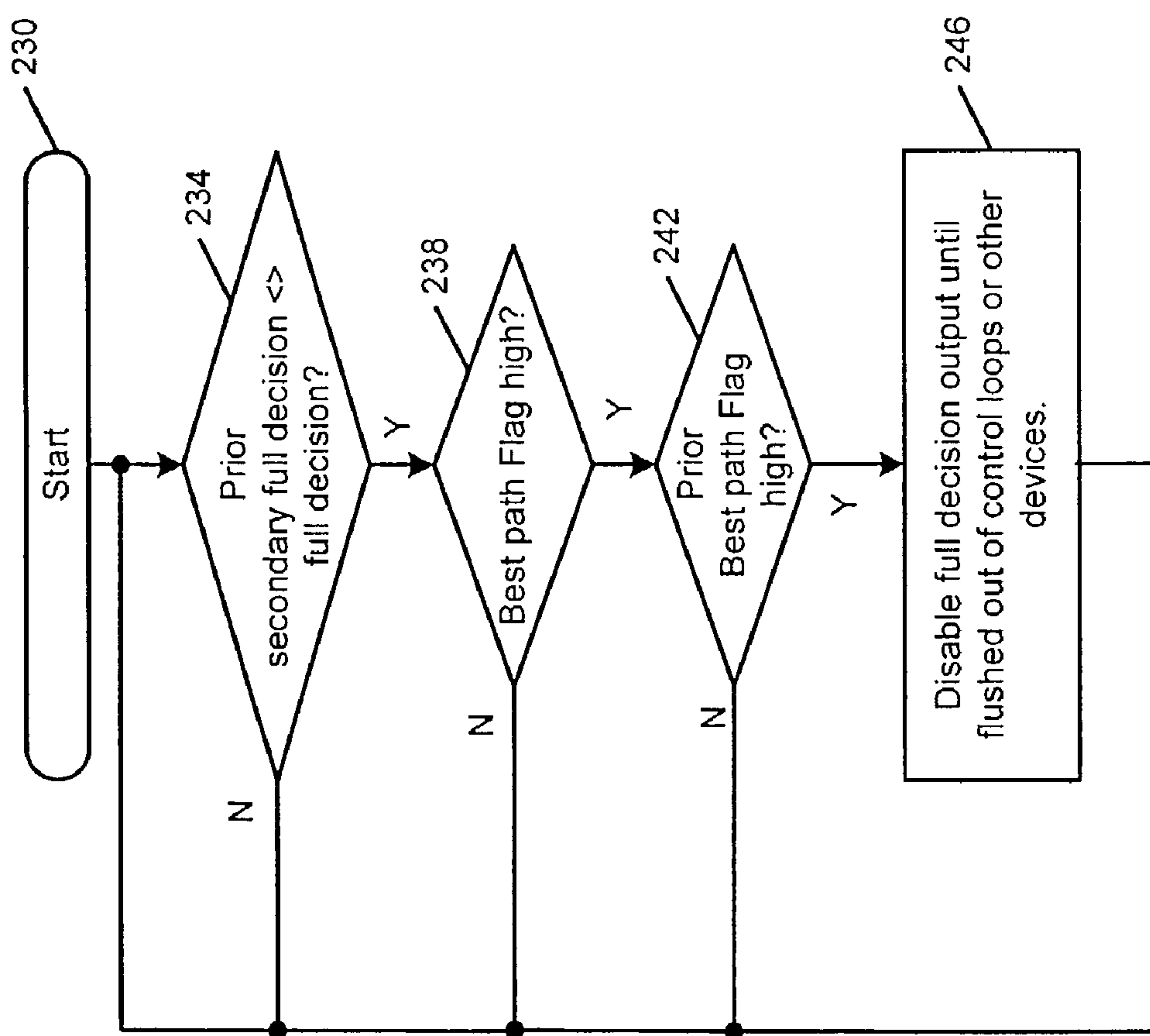
**FIG. 8**



**FIG. 9**



**FIG. 10**



**FIG. 11**



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**METHOD AND APPARATUS FOR  
DETECTING VITERBI DECODER ERRORS  
DUE TO QUASI-CATASTOPHIC SEQUENCES**

FIELD OF THE INVENTION

The present invention relates to communications channels with forward error correction (FEC), and more particularly to communications channels that include Viterbi decoders.

BACKGROUND OF THE INVENTION

As data storage densities and data transmission rates increase, the ability of hardware devices to correctly recognize binary data diminishes. Many communications systems perform forward error correction (FEC) to improve data transmission accuracy and to ensure data integrity. FEC helps reduce bit error rates (BER) in applications such as data storage, digital video broadcasts, and wireless communications.

Convolutional coding and block coding are two forms of FEC. Block coding typically adds redundant bits to a message. For example, parity bits are added to ensure an even sum. If an odd sum is received, an error is detected. In convolutional coding, a transmitted stream is generated from an input stream. A Viterbi decoder is used to decode the received stream to identify a most probable transmitted stream, which is used to recover the input stream.

Referring now to FIG. 1, a first device 10-1 communicates with a second device 10-2 over a communications channel 12. As can be appreciated, the devices 10-1 and 10-2 are simplified for discussion purposes. Additional signal processing is typically performed before and/or after the convolutional encoding and/or Viterbi decoding.

The communications channel can be hardwired or wireless. For example, the communications channel 12 can be an Ethernet network, a wireless local area network, a bus for a hard drive, etc. The first device 10-1 includes components 14-1 that provide an input stream to a convolutional encoder 16-1 and that receive a decoded stream from a Viterbi decoder 18-1. Likewise, the device 10-2 includes components 14-2 that provide an input stream to a convolutional encoder 16-2 and that receive a decoded stream from a Viterbi decoder 18-2. The components 14-1 of the first device 10-1 may be similar to and/or different than the components 14-2 of the second device 10-2. The convolutional encoders 16 transform the input stream into a transmitted stream before the data is output onto the communications channel 12. The Viterbi decoders 18 decode the received stream to recover a most probable transmitted stream.

For example, a rate-1/2 convolutional code transmits 2 output bits for each input bit. Referring now to FIG. 2, a trellis 20 is typically used to generate the rate-1/2 convolutional code. The trellis 20 includes four states (00, 01, 10 and 11). At each point, the trellis 20 splits into two paths. An upper path represents a 0 input and a lower path represent a 1 input. An initial state of 00 is presumed. Using the trellis 20 in FIG. 2, an input stream of 1101 generates an output of 11101101. In other words, the MSB of the input stream (1) corresponds to 11 in the transmitted stream. The 2<sup>nd</sup> MSB of the input stream (1) corresponds to 10 in the transmitted stream. The 3<sup>rd</sup> MSB of the input stream (0) corresponds to 11 in the transmitted stream. The LSB of the input stream (1) corresponds to 01 in the transmitted stream.

A received stream must be decoded. Some decoders use a Viterbi algorithm to decode the received stream. The

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Viterbi algorithm compares the received stream to all possible transmitted streams and selects the transmitted stream that is closest to the received stream. The transmitted stream that is selected by the Viterbi algorithm has a minimum number of bits that are different from the received stream— or a minimum bit distance. Once the most probable transmitted stream is identified, the input stream is generated from the selected trellis path.

Referring now to FIG. 3, to decode an input sequence of 10101010, a trellis 24 is used. The distance between each pair of received bits and the corresponding bits in the trellis 24 (or possible transmitted bits) are identified. For example, the 1 on the path AB results from the comparison of the received bits 10 to the bits 00 on the AB path. The received bits 10 differ from the trellis bits 00 for AB by one bit position.

If there are two paths that end at the same point or state, the Viterbi decoder selects the path with the minimum bit distance. If the two paths have the same distance, either path can be selected. In other words, the probability of decoding is the same for each path. In this particular example, the path through ACGJL in the trellis 24 has a bit distance of 2. The path ACGJL is generated by an input of 1100. The input of 1100 into the trellis 20 in FIG. 2 would correspond to an output of 11101110, which also has a bit distance of 2 from the received word. While a rate-1/2 convolutional code was shown, other rate convolutional codes may be used by Viterbi decoders.

Some conventional Viterbi decoders provide both a full decision output and an early decision output. The early decision output may be used by one or more control loops such as baseline loops, timing loops, gain loops and finite impulse response (FIR) adaptation loops. The early decision output may be used by the control loops to generate error signals. If the early decision output is incorrect, these control loops will cause errors. Therefore, the Viterbi decoder should not output the early decision output to these control loops when the early decision output is incorrect.

For example, for magnetic recording equalization targets containing a (1+D) factor, quasi-catastrophic sequences correspond to runs of alternating 1's and 0's that exceed a path memory depth of the Viterbi decoder that is matched to the equalization target. For equalization targets with a (1+D) factor, bit sequences with long transition runs can cause problems with the early decision output. For example, a sequence +-+--+--+--+--+--+--+--+--+ can be decoded to either +-+--+--+--+--+--+--+--+--+ or +-+--+--+--+--+--+--+--+--+-. For an all positive target, e.g. 4+6D+3D<sup>2</sup>+2D+1 D<sup>4</sup>, an output of a reconstruction filter can be either ?,?,?,0,0,0,-8,-12,-14,-16,-8,-4,-2,0,0,0,0,0 or ?,?,?,0,0,8,12,14,16,8,4,2,0,0,0,0,0,0. This incorrect early decision output would adversely impact the performance of the control loops that use the early decision output.

The Viterbi decoder makes the early decision errors when there is a tie between two different paths that have the same path metric value or bit distance. The tie is broken by deterministically selecting one best path over the other based on the current state of the path. A path is denoted as follows:

$$(u_F, u_{F-1}, \dots, u_E, u_{E-1}, \dots, u_1, u_0); m$$

where index F denotes the full decision depth. Index E denotes the early decision depth. Each variable  $u_i \in (-1, 1)$  denotes a bit in the Viterbi path memory and m is the path metric value for the path. The current state of the path for a 16 state trellis is given by bits  $u_0, u_1, U_2, U_3$ .



For example, using equalization target  $H(D)=(1+D)G(D)$ , there is a tie in the path metric between the two best paths  $P_A$  and  $P_B$  at time  $i$ :

$$P_{A,i}=(?, ?, \dots, ?, +1, -1, +1, -1, +1, -1, +1, -1, \underline{+1}, -1, +1, +1, +1, -1, +1, -1, +1, -1, +1);m$$

$$P_{B,i}=(?, ?, \dots, ?, -1, +1, -1, +1, -1, +1, -1, +1, \underline{-1}, +1, +1, +1, -1, +1, -1, +1, -1, +1, -1);m$$

The underscored bits represent the early decision output for respective paths  $P_A$  and  $P_B$ . If the Viterbi decoder at time  $i$  selects path  $P_A$  as the winner, then the early decision output is  $x_i=1$ .

For time  $i+1$ , the winning branch for path  $P_A$  corresponds to  $-1$  and the winning branch for path  $P_B$  corresponds to  $+1$ . At time  $t=i+1$ , the paths  $P_A$  and  $P_B$  are as follows:

$$P_{A,i+1}=(?, ?, \dots, ?, +1, -1, +1, -1, +1, -1, +1, -1, \underline{+1}, -1, +1, +1, +1, -1, +1, -1, +1, -1, +1);m$$

$$P_{B,i+1}=(?, ?, \dots, ?, -1, +1, -1, +1, -1, +1, -1, +1, \underline{-1}, +1, +1, +1, -1, +1, -1, +1, -1, +1, -1);m$$

Since the two paths  $P_A$  and  $P_B$  were tied at time  $i$  and the branch metrics for each path are equal, the paths  $P_A$  and  $P_B$  will be tied at time  $i+1$  as well. At time  $i$ , the leading state for path  $P_A$  was  $(+1, -1, +1, -1)$  and the leading state for path  $P_B$  was  $(-1, +1, -1, +1)$ . At time  $i+1$ , however, the leading state for path  $P_A$  is  $(-1, +1, -1, +1)$  and the leading state for path  $P_B$  is  $(+1, -1, +1, -1)$ .

Since the Viterbi decoder selected the path with leading state  $(+1, -1, +1, -1)$  when there was a tie between the two at time  $i$ , the Viterbi decoder will do the same at time  $t=i+1$ . Therefore, the path  $P_B$  will be the winner at time  $i+1$  and the early decision output will be  $x_{i+1}=1$ . If this continues for a few cycles, the output sequence would be  $+1, +1, +1, +1, +1$  for this segment. However, the correct output sequence should be  $+1, -1, +1, -1, +1$ .

### SUMMARY OF THE INVENTION

A Viterbi decoder includes an early decision generator that generates an early decision output. An error detector detects errors in the early decision output and generates a disable signal when the early decision output errors are detected.

In other features, a secondary early decision generator generates a secondary early decision output. The error detector includes a comparing circuit that disables a prior early decision output if the secondary early decision output is different than the prior early decision output. The comparing circuit includes a delay circuit that delays the early decision output to provide the prior early decision output. The comparing circuit further includes an XOR gate that includes a first input that receives the secondary early decision output and a second input that receives the prior early decision output.

In yet other features, a reconstruction filter and error signal generator communicates with the Viterbi decoder and generates error signals. A hold circuit communicates with the error detector and disables the error signals until the early decision output with errors passes out of the reconstruction filter and error signal generator. The secondary early decision output includes at least one bit that is temporally closer to the full decision output than the early decision output.

In other features, a best path flag generator generates a best path flag when the Viterbi decoder identifies two best paths having the same path metric. A comparing circuit

disables the early decision output if a prior secondary early decision output is different than the early decision output, the best path flag is true and a prior best path flag is true. A reconstructive filter and error signal generator communicates with the Viterbi decoder and generates error signals. A hold circuit communicates with the error detector and disables the error signals until the early decision output with errors passes out of the reconstruction filter and error signal generator. The comparing circuit includes at least one of a delay circuit, an XOR gate and an AND gate.

Another Viterbi decoder according to the present invention identifies errors in a full decision output. A full decision generator generates the full decision output. An error detector that detects errors in said full decision output and that generates a disable signal when said full decision output errors are detected.

Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

### BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. 1 illustrates a communications channel and devices with Viterbi decoders;

FIG. 2 illustrates a four state trellis for a 1/2-rate convolutional encoder according to the prior art;

FIG. 3 illustrates a four state trellis used to calculate a minimum distance according to the prior art;

FIG. 4 is a functional block diagram of an early decision output error detector according to the present invention;

FIG. 5 illustrates steps that are performed by the early decision output error detector in FIG. 4;

FIG. 6 is a functional block diagram of another early decision output error detector according to the present invention;

FIG. 7 illustrates steps that are performed by the early decision output error detector in FIG. 6;

FIG. 8 is a functional block diagram of a full decision output error detector according to the present invention;

FIG. 9 illustrates steps that are performed by the full decision output error detector in FIG. 8;

FIG. 10 is a functional block diagram of another full decision output error detector according to the present invention; and

FIG. 11 illustrates steps that are performed by the full decision output error detector in FIG. 10.

### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description of the preferred embodiment(s) is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses. For purposes of clarity, the same reference numbers will be used in the drawings to identify the same elements.

Referring now to FIG. 4, a first early decision error detector 48 according to the present invention is shown. A Viterbi decoder 50 receives data from a finite impulse response (FIR) filter 54. The output of the FIR filter 54 is also connected to a delay device 58 that inserts one or more



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delay units. The delay device **58** may match the delays of the Viterbi decoder **50**. The Viterbi decoder **50** provides a full decision output and an early decision output. The Viterbi decoder **50** also generates a secondary early decision output that will be described further below.

The early decision output is transmitted to a delay device **64** and to a reconstruction filter and error signal generator **68**, which also receives an output of the delay device **58**. The reconstruction filter of the reconstruction filter and error signal generator **68** uses the early decision Viterbi output to reconstruct an ideal noise free Viterbi detector input. For example, if the Viterbi detector **50** is matched to an equalization target  $H(D)$ , then the reconstruction filter convolves the Viterbi detector output with the equalization target  $H(D)$ . The error signal generator of the reconstruction filter and error signal generator **68** takes the difference between the reconstruction filter output and the output of the delay device **58**.

An output of the delay device **64** is input to an XOR gate **72**. The secondary early decision output is also input to the XOR gate **72**. An output of the XOR gate **72** is input to a hold circuit **76**, which holds the output of the XOR gate **72** for  $x$  cycles. The number of cycles  $x$  is related to the number of cycles that are required to pass the early decision output with errors out of the reconstruction filter and error signal generator **68**.

The output of the hold circuit **76** controls a multiplexer **80**, which selects between a 0 input and the output of the reconstruction filter and error signal generator **68**. When the output of the hold circuit **76** is high, the multiplexer **80** selects the 0 input to disable error signals that are based on the early decision output. When the output of the hold circuit **76** is low, the multiplexer **80** enables the error signal outputs of the reconstruction filter and error signal generator **68**. In other words, when the current secondary early decision output and the prior early decision output do not match, the XOR gate **72** outputs a high signal to the hold circuit **76**, which disables the error signal outputs of the reconstruction filter and error signal generator **68**. As a result, the bad early decision output will not impact the control loops. The hold circuit **76** continues to disable the early decision output until the effects of the early decision output error pass out of the reconstruction filter and error signal generator **68**.

The secondary early decision output is preferably one or more bits temporally closer to the full decision depth than the early decision outputs, although other bits may be used. The secondary early decision output is compared to the prior early decision output. If the second early decision output and the prior early decision output are different, then one of the bits was decoded in error and the prior early decision output is invalid. If the early decision output is used for error signal generation, the error signals that use the invalid early decision output are preferably reset.

The solution will be demonstrated using the same path memories that were used above. In addition to underlining the early decision output, the selected secondary early decision is double underlined. At time  $t=i$ , the paths  $P_A$  and  $P_B$  have the following values:

$$P_{A,i}=(?, ?, \dots, ?, +1, -1, +1, -1, +1, -1, +1, -1, \underline{\underline{\pm 1}}, -1, +1, +1, +1, -1, +1, -1, +1, -1, +1);m$$

$$P_{B,i}=(?, ?, \dots, ?, -1, +1, -1, +1, -1, +1, -1, +1, \underline{\underline{\pm 1}}, -1, +1, +1, +1, -1, +1, -1, +1, -1, -1);m$$

The early decision output is the same as before,  $x_i=1$  and the secondary output at time  $i$  is  $y_i=-1$ . At time  $i+1$ , the two paths  $P_A$  and  $P_B$  have the following values:

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$$P_{A,i}=(?, ?, \dots, ?, +1, -1, +1, -1, +1, -1, +1, -1, \underline{\underline{\pm 1}}, -1, +1, +1, +1, -1, +1, -1, +1, -1, +1);m$$

$$P_{B,i}=(?, ?, \dots, ?, -1, +1, -1, +1, -1, +1, -1, +1, -1, \underline{\underline{\pm 1}}, -1, +1, +1, +1, -1, +1, -1, +1, -1, -1);m$$

As before, the early decision output is  $x_{i+1}=1$  and the secondary early decision output is  $y_{i+1}=-1$ . The current secondary early decision output  $y_{i+1}=-1$  is compared to the early decision output from the last clock cycle  $x_i=1$ . These two outputs should be the same. If the two outputs are different, one of the two bits is erroneous. Therefore, the early decision  $x_i$  is declared invalid. If the early decision output is used to generate error signals, the error signals are reset for the number of cycles that the early decision output is used.

Referring now to FIG. 5, steps for identifying early decision output errors are shown. Control begins in step **82**. In step **84**, the early decision output error detector determines whether the secondary early decision output is different that the prior early decision output. If true, the early decision output error detector disables the early decision output in step **86** until the early decision output error has been flushed from the reconstruction filter and error signal generator **68**.

Instead of using a secondary early decision output with path memory that is larger than the early decision output, it is also possible to use a secondary early decision output with a path memory that is smaller than the early decision output. The secondary early decision output is delayed instead of the early decision output before the two outputs are compared. This approach allows the error signal to be reset earlier.

Referring now to FIG. 6, the Viterbi decoder **50** may also provide a best path flag in addition to the other outputs described above. The secondary early decision is output to a delay device **100**, which has an output that is connected to the XOR gate **72**. The early decision output is also connected to the XOR gate **72**. An output of the XOR gate is input to an AND gate **104**. A second input of the AND gate **104** is connected to the best path flag. The best path flag is also input to a delay device **106**. An output of the AND gate is input to an AND gate **108**, which has another input that is connected to the delay device **106**.

The best path function of the Viterbi decoder **50** selects a specific path only when there is a tie between two states (corresponding to a quasi-catastrophic sequence). Further, the best path flag is high only if the current path that is selected was selected using the best path function. The secondary early decision output in FIG. 6 preferably has a path delay of one less than the early decision output.

A problem arises when there is a tie between the two best path metrics and they both belong to the quasi-catastrophic sequence  $-+-+--+-+$ . In this case, the Viterbi decoder **50** will always select the path that ends in a particular state. For example, the two best states are  $(+--+)$  and  $(-+-+)$  and there is a tie. The Viterbi decoder **50** may select state  $(-+-+)$  using the best path function.

The best path that is selected when there is a tie is denoted as  $\hat{P}$ . If there is a tie between the states at times  $i$  and  $i+1$ , the Viterbi decoder **50** will choose the same state as the best state at times  $i$  and  $i+1$ . This means that there will be a change in the bit sequence. The secondary output is hardwired to path  $\hat{P}$  at a path memory depth of one less than that of the early decision output.

It is impossible to know which bit is correct. The incorrect bit will influence the control loops until it passes out of the reconstruction filter and error signal generator **68**. Therefore, the error signals generated by the control loops are disabled



when this occurs. The loops are disabled by resetting the error signals when the best path at times  $i$  and  $i-1$  is  $\hat{P}$  and the early decision output at time  $i$  is different than the prior secondary early decision (with path memory **1** less than early decision) at time  $i-1$ . Since resetting the error signal is conditioned on the best path being  $\hat{P}$  at time  $i-1$ , the secondary early decision can be hard wired to the bit in the sequence corresponding to path  $\hat{P}$ .

For a 16 state Viterbi, a 16-1 MUX operation is not required to obtain the error signal output. More generally, for an  $m$ -state Viterbi decoder, an  $m-1$  MUX operation is not required, which is normally required to obtain an early decision output from a Viterbi decoder. The best path flag signal goes high when the best path function of the Viterbi decoder selects the path beginning with state  $\hat{P}$ . The signal can then be used to verify that the secondary early decision output corresponds to the maximum likelihood path at that time. The error detector in FIG. 6 has the benefit of using a secondary early decision with path memory one shorter than the Viterbi decoder.

Referring now to FIG. 7, steps that are performed by the alternate early decision output error detector are shown. Control begins in step **130**. In step **132**, the alternate early decision output error detector determines whether the prior secondary early decision output is different than the current early decision output. If true, then the alternate early decision output error detector determines whether the best path flag is high in step **138**. If true, then the alternate early decision output error detector determines whether the prior best path flag is high. If true, then the alternate early decision output error detector disables the early decision output until it passes out of the reconstruction filter **68**.

Referring now to FIG. 8, a first full decision error detector **148** according to the present invention is shown and has operation that is similar to the early decision error detectors described above. A Viterbi decoder **150** receives data from a finite impulse response (FIR) filter **154**. The Viterbi decoder **150** provides a full decision output. The Viterbi decoder **150** also generates a secondary full decision output that will be described further below.

The full decision output is transmitted to a delay device **164** and to control loops or other devices **168**. An output of the delay device **164** is input to an XOR gate **172**. The secondary full decision output is also input to the XOR gate **172**. An output of the XOR gate **172** is input to a hold circuit **176**, which holds the output of the XOR gate **172** for  $x$  cycles. The number of cycles  $x$  is related to the number of cycles that are required to pass the full decision output with errors out of the control loops or other devices **168**.

The output of the hold circuit **176** controls a multiplexer **180**, which selects between a 0 input and the output of the control loops or other devices **168**. When the output of the hold circuit **176** is high, the multiplexer **180** selects the 0 input to disable error signals that are based on the full decision output. When the output of the hold circuit **176** is low, the multiplexer **180** enables outputs of the control loops or other devices **168**. In other words, when the current secondary full decision output and the prior full decision output do not match, the XOR gate **172** outputs a high signal to the hold circuit **176**, which disables the outputs of the control loops or other devices **168**. As a result, the bad full decision output will not have an adverse impact. The hold circuit **176** continues to disable the full decision output until the effects of the full decision output with errors passes out of the control loops or other devices **168**.

The secondary full decision output is preferably one or more bits that are temporally older than the full decision

depth, although other bits may be used. The secondary full decision output is compared to the prior full decision output. If the second full decision output and the prior full decision output are different, then one of the bits was decoded in error and the prior full decision output is invalid. If the full decision output is used for error signal generation, the error signals that use the invalid full decision output are preferably reset.

Referring now to FIG. 9, steps for identifying full decision output errors are shown. Control begins in step **182**. In step **184**, the full decision output error detector determines whether the secondary full decision output is different than the prior full decision output. If true, the full decision output error detector disables the full decision output in step **186** until the full decision output error has been flushed from the control loops or other devices **168**.

Instead of using a secondary full decision output with path memory that is larger or longer than the full decision output, it is also possible to use a secondary full decision output with a path memory that is smaller than the full decision output. The secondary full decision output is delayed instead of the full decision output before the two outputs are compared. This approach allows the error signal to be reset earlier.

Referring now to FIG. 10, the Viterbi decoder **150** may also provide a best path flag in addition to the other outputs described above. The secondary full decision is output to a delay device **200**, which has an output that is connected to the XOR gate **172**. The full decision output is also connected to the XOR gate **172**. An output of the XOR gate is input to an AND gate **204**. A second input of the AND gate **204** is connected to the best path flag. The best path flag is also input to a delay device **206**. An output of the AND gate is input to an AND gate **208**, which has another input that is connected to the delay device **206**.

The best path function of the Viterbi decoder **150** selects a specific path only when there is a tie between two states (corresponding to a quasi-catastrophic sequence). Further, the best path flag is high only if the current path that is selected was selected using the best path function. The secondary full decision output in FIG. 10 preferably has a path delay of one less than the full decision output.

Referring now to FIG. 11, steps that are performed by the alternate full decision output error detector are shown. Control begins in step **230**. In step **232**, the alternate full decision output error detector determines whether the prior secondary full decision output is different than the current full decision output. If true, then the alternate full decision output error detector determines whether the best path flag is high in step **238**. If true, then the alternate full decision output error detector determines whether the prior best path flag is high. If true, then the alternate full decision output error detector disables the full decision output until it passes out of the control loops or other devices **168**.

Those skilled in the art can now appreciate from the foregoing description that the broad teachings of the present invention can be implemented in a variety of forms. Therefore, while this invention has been described in connection with particular examples thereof, the true scope of the invention should not be so limited since other modifications will become apparent to the skilled practitioner upon a study of the drawings, the specification and the following claims.

What is claimed is:

1. A Viterbi decoder that identifies errors in an early decision output, comprising:
  - an early decision generator that generates said early decision output; and



an error detector that detects errors in said early decision output and that generates a disable signal when said early decision output errors are detected.

2. The Viterbi decoder of claim 1 further comprising a secondary early decision generator that generates a secondary early decision output.

3. The Viterbi decoder of claim 2 wherein said error detector includes a comparing circuit that disables a prior early decision output if said secondary early decision output is different than said prior early decision output.

4. The Viterbi decoder of claim 3 wherein said comparing circuit includes a delay circuit that delays said early decision output to provide said prior early decision output.

5. The Viterbi decoder of claim 1 further comprising:

a reconstruction filter and error signal generator that communicates with said Viterbi decoder and that generates error signals; and

a hold circuit that communicates with said error detector and that disables said error signals until said early decision output with errors passes out of said reconstruction filter and error signal generator.

6. The Viterbi decoder of claim 2 wherein said secondary early decision output includes at least one bit that is temporally closer to said full decision output than said early decision output.

7. The Viterbi decoder of claim 2 further comprising a best path flag generator that generates a best path flag when said Viterbi decoder identifies two best paths having the same path metric.

8. The Viterbi decoder of claim 7 further comprising a comparing circuit that disables said early decision output if a prior secondary early decision output is different than said early decision output, said best path flag is true and a prior best path flag is true.

9. The Viterbi decoder of claim 8 further comprising:

a reconstructive filter and error signal generator that communicates with said Viterbi decoder and that generates error signals; and

a hold circuit that communicates with said error detector and that disables said error signals until said early decision output with errors passes out of said reconstruction filter and error signal generator.

10. A Viterbi decoder that identifies errors in an early decision output, comprising:

an early decision generator that generates said early decision output;

a secondary early decision generator that generates a secondary early decision output; and

an error detector that detects errors in said early decision output and that includes a comparing circuit that generates a disable signal if said secondary early decision output is different than said prior early decision output.

11. The Viterbi decoder of claim 10 wherein said comparing circuit includes a delay circuit that delays said early decision output to provide said prior early decision output.

12. The Viterbi decoder of claim 10 further comprising a hold circuit that receives said disable signal.

13. The Viterbi decoder of claim 12 further comprising:

a reconstruction filter and error signal generator that generates error signals, wherein said hold circuit disables said error signals until said early decision output with errors passes out of said reconstruction filter and error signal generator.

14. The Viterbi decoder of claim 10 wherein said secondary early decision output includes at least one bit that is temporally closer to said full decision output than said early decision output.

15. A Viterbi decoder that identifies errors in an early decision output, comprising:

an early decision generator that generates said early decision output;

a secondary early decision generator that generates a secondary early decision output;

a best path flag generator that generates a best path flag when said Viterbi decoder identifies two best paths having the same path metric; and

an error detector that detects errors in said early decision output and that includes a comparing circuit that generates a disable signal if a prior secondary early decision output is different than said early decision output, said best path flag is true and a prior best path flag is true.

16. The Viterbi decoder of claim 15 further comprising: a reconstruction filter and error signal generator that communicates with said Viterbi decoder and that generates error signals; and

a hold circuit that communicates with said error detector and that holds said disable signal until said early decision output with errors passes out of said reconstruction filter and error signal generator.

17. A Viterbi decoder that identifies errors in an early decision output, comprising:

early decision generating means for generating said early decision output; and

error detecting means for detecting errors in said early decision output and for generating a disable signal when said early decision output errors are detected.

18. The Viterbi decoder of claim 17 further comprising secondary early decision generating means for generating a secondary early decision output.

19. The Viterbi decoder of claim 18 wherein said error detecting means includes comparing means for disabling a prior early decision output if said secondary early decision output is different than said prior early decision output.

20. The Viterbi decoder of claim 19 wherein said comparing means includes delay means for delaying said early decision output to provide said prior early decision output.

21. The Viterbi decoder of claim 17 further comprising: reconstruction filter and error signal generating means for communicating with said Viterbi decoder and for generating error signals; and

hold means for communicating with said error detecting means and for disabling said error signals until said early decision output with errors passes out of said reconstruction filter and error signal generating means.

22. The Viterbi decoder of claim 18 wherein said secondary early decision output includes at least one bit that is temporally closer to said full decision output than said early decision output.

23. The Viterbi decoder of claim 18 further comprising best path flag generating means for generating a best path flag when said Viterbi decoder identifies two best paths having the same path metric.

24. The Viterbi decoder of claim 23 further comprising comparing means for disabling said early decision output if a prior secondary early decision output is different than said early decision output, said best path flag is true and a prior best path flag is true.

25. The Viterbi decoder of claim 24 further comprising: reconstructive filter and error signal generating means for communicating with said Viterbi decoder and for generating error signals; and

hold means for communicating with said error detector and for disabling said error signals until said early



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decision output with errors passes out of said reconstruction filter and error signal generating means.

**26.** A Viterbi decoder that identifies errors in an early decision output, comprising:

early decision generating means for generating said early decision output;

secondary early decision generating means for generating a secondary early decision output; and

error detecting means for detecting errors in said early decision output and that includes comparing means for generating a disable signal if said secondary early decision output is different than said prior early decision output.

**27.** The Viterbi decoder of claim **26** wherein said comparing means includes delay means for delaying said early decision output to provide said prior early decision output.

**28.** The Viterbi decoder of claim **26** further comprising hold means for receiving said disable signal.

**29.** The Viterbi decoder of claim **28** further comprising: reconstruction filter and error signal generating means for generating error signals, wherein said hold means disables said error signals until said early decision output with errors passes out of said reconstruction filter and error signal generating means.

**30.** The Viterbi decoder of claim **26** wherein said secondary early decision output includes at least one bit that is temporally closer to said full decision output than said early decision output.

**31.** A Viterbi decoder that identifies errors in an early decision output, comprising:

early decision generating means for generating said early decision output;

secondary early decision generating means for generating a secondary early decision output;

best path flag generating means for generating a best path flag when said Viterbi decoder identifies two best paths having the same path metric; and

error detecting means for detecting errors in said early decision output and that includes comparing means for generating a disable signal if a prior secondary early decision output is different than said early decision output, said best path flag is true and a prior best path flag is true.

**32.** The Viterbi decoder of claim **31** further comprising: reconstruction filter and error signal generating means for communicating with said Viterbi decoder and for generating error signals; and

hold means for communicating with said error detecting means and for holding said disable signal until said early decision output with errors passes out of said reconstruction filter and error signal generating means.

**33.** A method for operating a Viterbi decoder that identifies errors in an early decision output, comprising:

generating said early decision output;

detecting errors in said early decision output; and

generating a disable signal when said early decision output errors are detected.

**34.** The method of claim **33** further comprising generating a secondary early decision output.

**35.** The method of claim **34** further comprising disabling a prior early decision output if said secondary early decision output is different than said prior early decision output.

**36.** The method of claim **35** further comprising delaying said early decision output to provide said prior early decision output.

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**37.** The method of claim **33** further comprising: generating error signals using a reconstruction filter and error signal generator that communicates with said Viterbi decoder; and

disabling said error signals until said early decision output with errors passes out of said reconstruction filter and error signal generator.

**38.** The method of claim **34** wherein said secondary early decision output includes at least one bit that is temporally closer to said full decision output than said early decision output.

**39.** The method of claim **34** further comprising generating a best path flag when said Viterbi decoder identifies two best paths having the same path metric.

**40.** The method of claim **39** further comprising disabling said early decision output if a prior secondary early decision output is different than said early decision output, said best path flag is true and a prior best path flag is true.

**41.** The method of claim **40** further comprising: generating error signals using a reconstructive filter and error signal generator that communicates with said Viterbi decoder; and

disabling said error signals until said early decision output with errors passes out of said reconstruction filter and error signal generator.

**42.** A method for operating a Viterbi decoder that identifies errors in an early decision output, comprising:

generating said early decision output;

generating a secondary early decision output;

detecting errors in said early decision output; and

generating a disable signal if said secondary early decision output is different than said prior early decision output.

**43.** The method of claim **42** further comprising delaying said early decision output to provide said prior early decision output.

**44.** The method of claim **42** further comprising disabling said error signals until said early decision output with errors passes out of a reconstruction filter and error signal generator.

**45.** The method of claim **42** wherein said secondary early decision output includes at least one bit that is temporally closer to said full decision output than said early decision output.

**46.** A method for operating a Viterbi decoder that identifies errors in an early decision output, comprising:

generating said early decision output;

generating a secondary early decision output;

generating a best path flag when said Viterbi decoder identifies two best paths having the same path metric;

detecting errors in said early decision output; and

generating a disable signal if a prior secondary early decision output is different than said early decision output, said best path flag is true and a prior best path flag is true.

**47.** The method of claim **46** further comprising:

generating error signals using a reconstruction filter and error signal generator that communicates with said Viterbi decoder; and

holding said disable signal until said early decision output with errors passes out of said reconstruction filter and error signal generator.

**48.** A Viterbi decoder that identifies errors in a full decision output, comprising:

a full decision generator that generates said full decision output; and



an error detector that detects errors in said full decision output and that generates a disable signal when said full decision output errors are detected.

49. The Viterbi decoder of claim 48 further comprising a secondary full decision generator that generates a secondary full decision output.

50. The Viterbi decoder of claim 49 wherein said error detector includes a comparing circuit that disables a prior full decision output if said secondary full decision output is different than said prior full decision output.

51. The Viterbi decoder of claim 50 wherein said comparing circuit includes a delay circuit that delays said full decision output to provide said prior full decision output.

52. The Viterbi decoder of claim 48 further comprising a hold circuit that disables said error signals for a predetermined period.

53. The Viterbi decoder of claim 49 wherein said secondary full decision output includes at least one bit that is temporally older than said full decision output.

54. The Viterbi decoder of claim 49 further comprising a best path flag generator that generates a best path flag when said Viterbi decoder identifies two best paths having the same path metric.

55. The Viterbi decoder of claim 54 further comprising a comparing circuit that disables said full decision output if a prior secondary full decision output is different than said full decision output, said best path flag is true and a prior best path flag is true.

56. The Viterbi decoder of claim 55 further comprising a hold circuit that disables said error signals for a predetermined period.

57. A Viterbi decoder that identifies errors in a full decision output, comprising:

a full decision generator that generates said full decision output;

a secondary full decision generator that generates a secondary full decision output; and

an error detector that detects errors in said full decision output and that includes a comparing circuit that generates a disable signal if said secondary full decision output is different than said prior full decision output.

58. The Viterbi decoder of claim 57 wherein said comparing circuit includes a delay circuit that delays said full decision output to provide said prior full decision output.

59. The Viterbi decoder of claim 57 further comprising a hold circuit that receives said disable signal.

60. The Viterbi decoder of claim 59 wherein said hold circuit disables said error signals for a predetermined period.

61. The Viterbi decoder of claim 57 wherein said secondary full decision output includes at least one bit that is temporally older than said full decision output.

62. A Viterbi decoder that identifies errors in a full decision output, comprising:

a full decision generator that generates said full decision output;

a secondary full decision generator that generates a secondary full decision output;

a best path flag generator that generates a best path flag when said Viterbi decoder identifies two best paths having the same path metric; and

an error detector that detects errors in said full decision output and that includes a comparing circuit that generates a disable signal if a prior secondary full decision output is different than said full decision output, said best path flag is true and a prior best path flag is true.

63. The Viterbi decoder of claim 62 further comprising a hold circuit that holds said disable signal for a predetermined period.

64. A Viterbi decoder that identifies errors in a full decision output, comprising:

full decision generating means for generating a full decision output; and

error detecting means for detecting errors in said full decision output and for generating a disable signal when said full decision output errors are detected.

65. The Viterbi decoder of claim 64 further comprising secondary full decision generating means for generating a secondary full decision output.

66. The Viterbi decoder of claim 65 wherein said error detecting means includes comparing means for disabling a prior full decision output if said secondary full decision output is different than said prior full decision output.

67. The Viterbi decoder of claim 66 wherein said comparing means includes delay means for delaying said full decision output to provide said prior full decision output.

68. The Viterbi decoder of claim 64 further comprising hold means for disabling said error signals for a predetermined period.

69. The Viterbi decoder of claim 65 wherein said secondary full decision output includes at least one bit that is temporally older than said full decision output.

70. The Viterbi decoder of claim 65 further comprising best path flag generating means for generating a best path flag when said Viterbi decoder identifies two best paths having the same path metric.

71. The Viterbi decoder of claim 70 further comprising comparing means for disabling said full decision output if a prior secondary full decision output is different than said full decision output, said best path flag is true and a prior best path flag is true.

72. The Viterbi decoder of claim 71 further comprising hold means for disabling said error signals for a predetermined period.

73. A Viterbi decoder that identifies errors in a full decision output, comprising:

full decision generating means for generating said full decision output;

secondary full decision generating means for generating a secondary full decision output; and

error detecting means for detecting errors in said full decision output and including comparing means for generating a disable signal if said secondary full decision output is different than said prior full decision output.

74. The Viterbi decoder of claim 73 wherein said comparing means includes delay means for delaying said full decision output to provide said prior full decision output.

75. The Viterbi decoder of claim 73 further comprising hold means for receiving said disable signal.

76. The Viterbi decoder of claim 75 wherein said hold means disables said error signals for a predetermined period.

77. The Viterbi decoder of claim 73 wherein said secondary full decision output includes at least one bit that is temporally older than said full decision output.

78. A Viterbi decoder that identifies errors in a full decision output, comprising:

full decision generating means for generating said full decision output;

secondary full decision generating means for generating a secondary full decision output;



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best path flag generating means for generating a best path flag when said Viterbi decoder identifies two best paths having the same path metric; and

error detecting means for detecting errors in said full decision output and that includes comparing means for generating a disable signal if a prior secondary full decision output is different than said full decision output, said best path flag is true and a prior best path flag is true.

79. The Viterbi decoder of claim 78 further comprising hold means for holding said disable signal for a predetermined period.

80. A method for operating a Viterbi decoder that identifies errors in a full decision output, comprising:

generating said full decision output;  
detecting errors in said full decision output; and  
generating a disable signal when said full decision output errors are detected.

81. The method of claim 80 further comprising generating a secondary full decision output.

82. The method of claim 81 further comprising disabling a prior full decision output if said secondary full decision output is different than said prior full decision output.

83. The method of claim 82 further comprising delaying said full decision output to provide said prior full decision output.

84. The method of claim 80 further comprising disabling said error signals for a predetermined period.

85. The method of claim 81 wherein said secondary full decision output includes at least one bit that is temporally closer to said full decision output than said full decision output.

86. The method of claim 81 further comprising generating a best path flag when said Viterbi decoder identifies two best paths having the same path metric.

87. The method of claim 86 further comprising disabling said full decision output if a prior secondary full decision

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output is different than said full decision output, said best path flag is true and a prior best path flag is true.

88. The method of claim 87 further comprising disabling said error signals for a predetermined period.

89. A method for operating a Viterbi decoder that identifies errors in a full decision output, comprising:

generating said full decision output;  
generating a secondary full decision output;  
detecting errors in said full decision output; and  
generating a disable signal if said secondary full decision output is different than said prior full decision output.

90. The method of claim 89 further comprising delaying said full decision output to provide said prior full decision output.

91. The method of claim 89 further comprising disabling said error signals for a predetermined period.

92. The method of claim 89 wherein said secondary full decision output includes at least one bit that is temporally closer to said full decision output than said full decision output.

93. A method for operating a Viterbi decoder that identifies errors in a full decision output, comprising:

generating said full decision output;  
generating a secondary full decision output;  
generating a best path flag when said Viterbi decoder identifies two best paths having the same path metric;  
detecting errors in said full decision output; and

generating a disable signal if a prior secondary full decision output is different than said full decision output, said best path flag is true and a prior best path flag is true.

94. The method of claim 93 further comprising:  
holding said disable signal for a predetermined period.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 7,107,514 B1  
APPLICATION NO. : 10/393640  
DATED : September 12, 2006  
INVENTOR(S) : Mats Oberg et al.

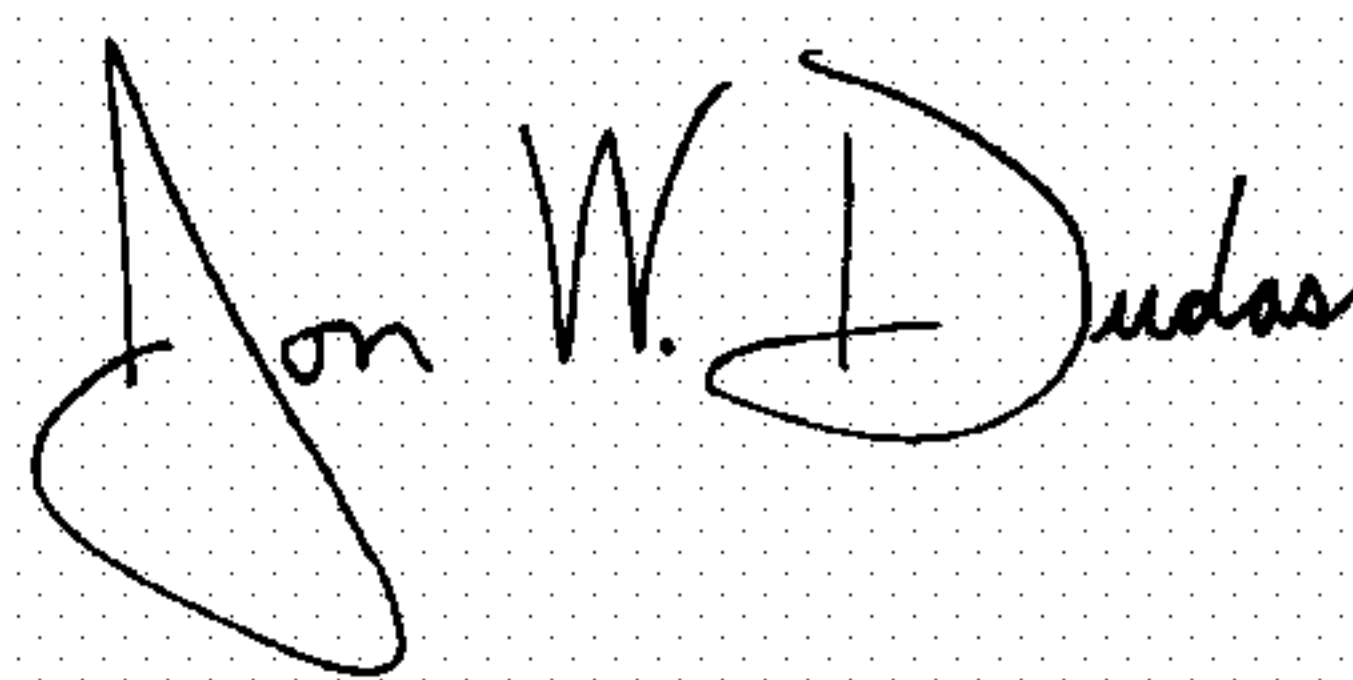
Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title Page: Delete "Quasi-Catastrophic" and insert --Quasi-Catastrophic--  
Column 2, Line 47: Delete "+-+-+-+--+-+--+-+--+-+" and insert  
-- +-+-+-+-----+-+-+-+--+-+--+-+ --  
Column 2, Line 49: Delete "2D" and insert -- 2D<sup>3</sup> --  
Column 2, Line 61: Delete " $U_{E-1}$ " and insert --  $u_{E-1}$  --  
Column 2, Line 67: Delete " $U_2, U_3$ " and insert --  $u_2, u_3$  --  
Column 3, Line 5: Delete the third "+1" after "+1" and insert -- -1 --  
Column 3, Line 7: Delete the second "+1" after "-1" and insert -- -1 --  
Column 3, Line 16: Delete "t=+1" and insert --t=i+1--  
Column 3, Line 19: Delete "(?,?,...,?,+1,-1,+1,-1,+1,-1,+1,-1,+1,-1,+1,+1,-1,+1,  
-1,+1,-1,+1)" and insert --(?,?,...,?,+1,-1,+1,-1,+1,-1,+1,-1,+1,  
-1,+1,-1,+1,-1,+1,-1,+1,-1,+1)-  
Column 3, Line 21: Delete "(?,?,...,?,-1,+1,-1,+1,-1,+1,-1,+1,-1,+1,+1,+1,-1,+1,  
-1,+1,-1)" and insert --(?,?,...,?,-1,+1,-1,+1,-1,+1,-1,+1,-1,+1,  
-1,+1,-1,+1,-1,+1,-1,+1,-1,+1)-  
Column 3, Line 26: Delete second "for path"  
Column 4, Line 11: Delete "inbention" and insert --invention--  
Column 5, Line 60: After "+1" delete the second "+1" and insert -- -1 --  
Column 5, Line 63: After "-1" delete the second "+1" and insert -- -1 --  
Column 6, Line 1: Delete "(?,?,...,?,+1,-1,+1,-1,+1,-1,+1,-1,+1,-1,+1,+1,-1,+1,  
-1,+1,-1,+1)" and insert --(?,?,...,?,+1,-1,+1,-1,+1,-1,+1,-1,+1,-1,+1,  
-1,+1,-1,+1,-1,+1,-1,+1,-1,+1)-  
Column 6, Line 4: Delete "(?,?,...,?,-1,+1,-1,+1,-1,+1,-1,+1,+1,+1,-1,+1,-1,+1,  
-1,+1,-1)" and insert "(?,?,...,?,-1,+1,-1,+1,-1,+1,-1,+1,-1,+1,-1,+1,  
-1,+1,-1,+1,-1,+1,-1,+1,-1,+1)-  
Column 6, Line 12: Delete "It" and insert --If--  
Column 6, Line 20: Delete "that" and insert --than--

Signed and Sealed this

Fifth Day of June, 2007



JON W. DUDAS

Director of the United States Patent and Trademark Office